

****Volume Title****

*ASP Conference Series, Vol. **Volume Number***

****Author****

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Testing the binary hypothesis for the formation and shaping of planetary nebulae

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Abstract. There is no quantitative theory to explain why a high 80% of all planetary nebulae are non-spherical. The *Binary Hypothesis* states that a companion to the progenitor of a central star of planetary nebula is required to shape the nebula and even for a planetary nebula to be formed at all. A way to test this hypothesis is to estimate the binary fraction of central stars of planetary nebulae and to compare it with that of the main sequence population. Preliminary results from photometric variability and the infrared excess techniques indicate that the binary fraction of central stars of planetary nebulae is higher than that of the main sequence, implying that PNe could preferentially form via a binary channel. This article briefly reviews these results and current studies aiming to refine the binary fraction.

1. Introduction

Although it is a short phase of stellar evolution, planetary nebulae (PNe) are objects of interest, both because they can be used to probe the physics of stars at a precise moment in their evolution, and because they are WD progenitors. In spite of their key role in Sun-like stars evolution, the mechanisms of their formation and shaping are uncertain to such an extent that we even doubt that they are really the product of all single Sun-like stars. Indeed, more than 80% (Parker et al. 2006; Jacoby et al. 2010) of PNe are non-spherical, showing structures such as lobes and jets that give an axisymmetric, point-symmetric or asymmetric shape to the nebula. The hypothesis traditionally used to account for these shapes has been the action of global magnetic fields during the super wind phase of an AGB star, diverting the gas being ejected to the equatorial plane. However, this hypothesis has been contested by Soker (2006) and Nordhaus et al. (2007), who argued that the magnetic field could not be sustained for long enough on a whole-star scale due to the coupling between the magnetic field and

the star rotation ; the field slows the rotation down and quenches itself. Another hypothesis to account for non-spherical shapes of PNe is the presence of a companion (e.g. Soker (1997)). The hypothesis according to which a companion is required to shape an non-spherical PN has been dubbed the *Binary Hypothesis* (De Marco 2009). To test it, a necessary step is to estimate the binary fraction of central stars of planetary nebulae (CSPNe). If the observed binary fraction of the CSPN population is superior to that of the putative parent population (the main sequence (MS) stars with mass $\approx 1-8 M_{\odot}$, Moe & De Marco 2006), this indicates that PNe are preferentially a binary phenomenon (see De Marco (2009) for a detailed review). This paper describes briefly past and present efforts aimed at estimating an unbiased binary fraction of CSPNe.

2. The binary fraction obtained using photometric variability

Periodic photometric variability of a binary CSPN is due to irradiation effect from the hot CSPN onto the companion, tidal deformations and eclipses (Bond 2000; Miszalski et al. 2009). Detecting photometric variability requires repeated observations of targets and can be done from the ground in non-photometric weather conditions. For this reason, it is an efficient binary-detection method and provides constantly new results. The main drawback of this method is that it is biased to small separations as irradiation effect, tidal deformations and eclipses all increase in intensity or frequency with decreasing separations.

Bond (2000) and Miszalski et al. (2009) already estimated close binary fractions of CSPNe of respectively 10-15% and 12-21% with binary periods $\lesssim 3$ days. Although these fractions are lower limits for the overall binary fraction, their comparison with the MS stars short-period binary fraction up to these these separations i.e. 5-7% (Duquennoy & Mayor 1991; Raghavan et al. 2010; De Marco et al. 2012) already reveals that more PNe are formed around binaries.

Hillwig et al. (these proceedings) are monitoring targets from the 2.5 kpc volume-limited sample of Frew (2008) to estimate a new fraction of close binaries. Although their method is similar, the sample is less biased than the previously used magnitude-limited samples and also deeper ($V < 21$). In a similar experiment, Jacoby et al. (2012) are monitoring 5-6 CSPNe within the Kepler satellite field of view to estimate an independent binary fraction. Their sample is statistically small ; however the CSPNe are observed with a precision never reached before (< 1 mmag).

3. The binary fraction obtained using red and infrared excess

The red/IR excess technique aims to detect the signature of a cool, unresolved companion by measuring the photometry of the hot CSPN. To do so, high precision absolute photometry needing photometric weather conditions in the B , V and I (or J) bands is required. This technique is fully described in De Marco et al. (2012). The measured $B - V$ color is compared to the expected $B - V$ for the CSPN temperature according to atmospheric stellar models (e.g. Rauch & Deetjen 2003) and allows us to determine the reddening, whereas the $V - I$ or $V - J$ colours allows us to measure the red/IR excess, which is the difference between the $V - I$ or $V - J$ colour expected for a single star at the CSPN temperature and the measured (de-reddened) one. If this difference is greater than the error on the photometric measurement, we list the object as a possible/probable

binary. Since companions cooler than $\approx M0-5$ are faint, we need excellent photometric precision. Once a binary fraction has been estimated, it can be compared to the MS one (Raghavan et al. 2010) only after undetected systems are accounted for. Using the *J*-band allows us to detect colder companions, while still not being contaminated by hot dust, although it requires a separate NIR observing run and is therefore time demanding.

Frew & Parker (2007) have used the photometry from the 2MASS and DENIS NIR surveys to determine a binary fraction $\approx 54\%$ but the detection bias was poorly quantified. De Marco et al. (2012) have used the method described above on a sample of 27 CSPNe and have found a similar debiased fraction $\approx 30\%$ from I-band data and $\approx 54\%$ from *J*-band data of a subset of 11 CSPNe in line with Frew & Parker (2007) result of 52-58%. These fractions are biased in that companions fainter than M3-4V in I and M5-6V in J are not detected. Before this fraction can be compared with that of the mother population (the F6V-G2V stars, see Raghavan et al. (2010) ; $50\pm4\%$), a second bias must be taken into account ; by design the CSPN survey does not include resolved binaries which are instead accounted for in the MS binary fraction. Once these biases are accounted for, De Marco et al. (2012) calculate a PN binary fraction of 70-100%. The uncertainty is large because the statistics are poor. These preliminary results will be confronted by the study of an additional 23 objects for which absolute photometry has been acquired at the NOAO 2.1m telescope in March 2011 as well as ≈ 30 objects for which *J* and *H*-band photometry has been obtained at the AAT 4m telescope in 2011 and the ANU 2.3m telescope in 2012. These new measurements should bring the sample to a statistically significant size and considerably reduce the error bars on the binary fraction. Recent surveys including *J*-band photometry will be analysed as well to extract the IR excess of other targets from the sample of Frew (2008).

4. The WD binary fraction and period distribution compared to those of the CSPN population

The comparison of binary CSPN and binary WD populations can supply us with further constraints of the binary hypothesis. De Marco et al. (2009) ascertained that there are similarities between the period distributions of CSPN and WDs, although our knowledge of both is too coarse to draw detailed conclusions. In particular, since we presume that *all* WDs come from the 1-8 M_{\odot} population the WD binary fraction should truly reflect that of the main sequence, and be different from that of the CSPN population. The WD binary fraction of 30-40% appears to be in line with that of the main sequence progenitor population (we recall that the progenitors of the entire WD sample have a median mass smaller than for a given CSPN and that the corresponding progenitor population binary fraction is therefore smaller as well, Raghavan et al. 2010). It remains to be seen what the CSPN overall binary fraction is and whether it is indeed much larger than for the putative main sequence population and in line with the hypothesis that there is a preferential binary channel for PN formation.

5. Conclusion

Estimating an unbiased binary fraction of CSPNe is crucial to the understanding of whether companions play a key role in shaping PNe. Photometric variability has al-

lowed us to determine a close binary fraction of $\approx 15\text{-}20\%$ and is still being refined on a new, less biased sample to understand the biases inherent to this method. The red/IR excess technique leads us to obtain a CSPN binary fraction of 70-100%, much larger than for the MS population. However, this number carries a large uncertainty for the moment due to the small sample size. Current studies based on optical and NIR photometry as well as the use of recent NIR surveys will double the sample size to constrain the CSPN binary fraction precisely enough to support or refute the hypothesis that PNe could emerge preferentially from binary star evolution.

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